MARYATT

Inductive Disturbances On Telephone Lines

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INDUCTIVE DISTURBANCES ON TELEPHONE LINES

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ELMER FAUNTLEROY MARYATT

ENTITLED INDUCTIVE DISTURBANCES ON TELEPHONE LINES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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_C_O_N_T_E_N_T_S_

THE INDUCTIVE DISTURBANCES ON TELEPHONE LINES DUE TO NEIGHBORING HIGH-TENSION CIRCUITS..

The problem of inductive disturbances on telephone lines due to adjacent high-tension circuits is becoming a matter of very great importance. For a time the telephone companies were unmolested, there being no disturbing influence to interfere with their successful operation. With the exception of cross talk between the wires themselves there was practically no inductive disturbances to contend with. The development of high-tension transmission systems has brought about disaster to many of the telephones which happened to be in their immediate vicinity. The electrification of the New York Central and the N.Y., N.H. & Hartford railroads rendered telephones in-operative for miles around. Other minor instances are on record such as one reported by John Parry at Union Siding near Lincoln, Illinois. There is in his vicinity a grounded telephone line which for one-half mile runs parallel to the 3300 volt transmission line. The telephone is out of service because of induction. It is such instances as these which are beginning to attract the attention of the telephone engineers and they begin to realize that before further development is carried on in high-tension work, something must be done for their protection. There has been but very little thorough investigation of this subject and it is the purpose of this thesis, primarily, to collect such data as has been obtained and to put it in a form such that it would be of use to one who in-

tended to carry on this investigation; and, secondarily, to perform such experiments as time will permit.

Alternating current systems, because of their use, have become divided into two large classes--

1. The transmission of power,

2. The transmission of intelligence.

The former is characterized by large currents, high pressures, and low frequencies, relatively large terminal reactions, wave length greater than the line length, the flow of energy in a given direction and inductive disturbances usually small. The later is characterized by small currents, low pressures (within the line itself), high frequencies, relatively small terminal reactions, wave lengths usually less than the line length, the flow of energy not in a given direction, and the inductive disturbances usually large. Each of these systems energize a portion of the surrounding ether, setting up both electric and magnetic fields which depend for their intensity on the potential, the number of phases, and on the number, size, and relative position of the wires. In the case where two of these circuits parallel each other, the ether is energized in common to both, and the greater inductive disturbances appear in the more sensitive of the two circuits. It is stated by Mr. F. F. Fowle that the greatest permissable current in a telephone receiver is 5×10^{-6} amperes, at 300 cycles, or 50×10^{-6} amperes at 25 cycles. It is therefore important that means of prevent-

ing these currents be studied, and before remedies are suggested the causes of these disturbing currents must be determined.

The methods by which disturbances in telephone circuits are set up are enumerated as follows:

1. By electro-magnetic induction
2. By electro-static induction
3. By leakage
4. By unbalanced lines and terminals.

The electro-magnetic induction is nothing more or less than transformer action as discovered by Faraday.

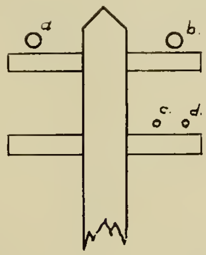


Fig. 1.

Fig. 1 shows the relative position of a single phase power line a,b and a telephone circuit c,d. The two views a and b may be regarded as the primary and the wires c,d the secondary of a transformer having an air core. In this case it may be seen that the intermittent lines of flux about the wires a,b will continually cut wires c,d and unless some means of prevention be used large disturbing currents will be set up in the telephone wires c and d. This is perhaps best described in a discussion of the electro-magnetic induction as given by Mr. F. F. Fowle before the A. I. E. E. at New York, October 28, 1904, and an abstract of his paper is given below.

The character of the magnetic field set up about two wires in space is shown by Fig. 2.

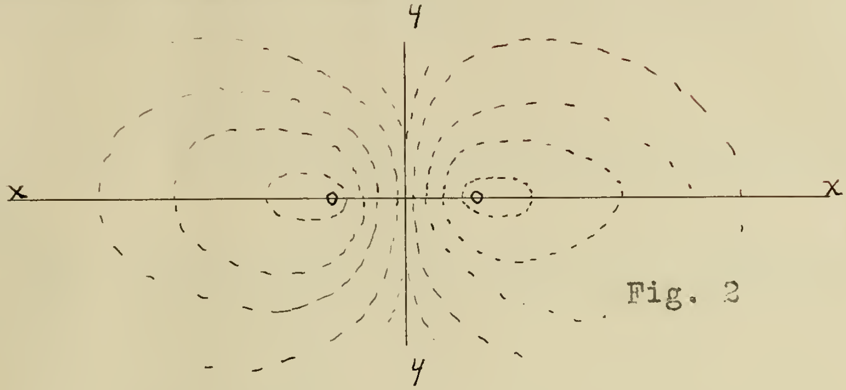


Fig. 2

The flux density diminishes very rapidly as the distance from the wires increases and this variation is shown in Fig. 3, which was plotted by Mr. Fowle.

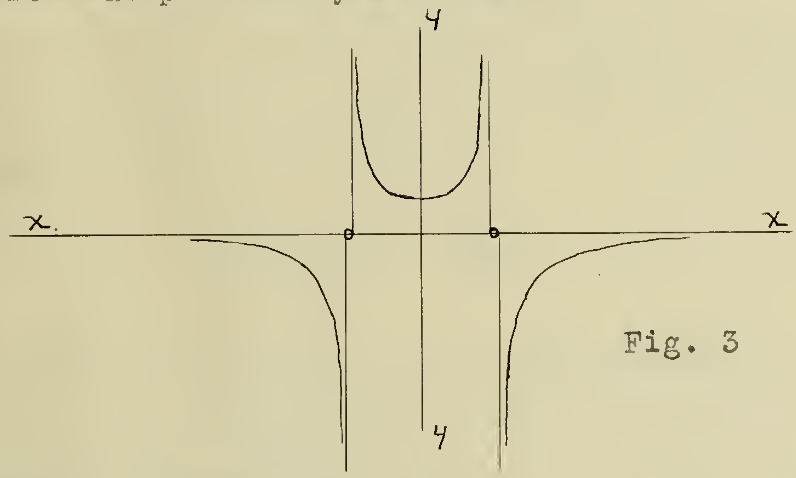


Fig. 3

It may be seen that the figure was plotted with the flux density in rectangular coordinants along the x-axis.

For a theoretical discussion of these figures consider a wire in free space, with radius r, carrying a current I. The work done in carrying a unit pole about the wire at a uniform distance a from the center of the wire is,--

$$W = 4\pi I = 2\pi a F.$$

where F is the magnetic force at a.

The force acts through a point, a, perpendicular to the plane containing the wire and the point, a. Therefore,--

$$F = \frac{2I}{a} = H$$

where H is the intensity of the magnetic field.

In a unit length of wire the total number of lines about the wire multiplied by the current is

$$N_1 = \int_r^{\infty} \frac{2\mu I^2}{X} dx.$$

where X is the radial distance from the wire and μ the permeability of the medium.

Assuming uniform current density through the section of the wire we have for the field intensity at a point, b, distant from the center of the wire

$$\frac{\pi b^2}{\pi r^2}\left(\frac{2I}{b}\right) = \frac{2Ib}{r^2},$$

and this intensity is due to the current enclosed within the circumference 2 b. The product between the current and the flux integrated between the limits b = 0 and b = r is

$$N_2 = \int_0^r \frac{2\mu_1 I^2 X^3}{r^4} dx. \qquad 5$$

where μ_1 is the magnetic permeability of the wire. The total number of linkages of flux with the current, multiplied by the current, is,-

$$N = N_1 + N_2 = \int_0^r \frac{2\mu_1 I^2 X^3}{r^4} dx. + \int_0^{\infty} \frac{2\mu I^2}{X} dx. \qquad 6$$

The inductance* is therefore--

$$L = \frac{1}{2}\mu_1 + \int_r^\infty \frac{2\mu}{x}\,dx \qquad 7$$

If there is a parallel wire in the field of the first wire distant r_{12} from it, the portion of total flux which is linked with it is

$$M = \int_{r_{12}}^\infty \frac{2\mu}{x}\,dx. \qquad 8$$

and this is the mutual resistance of the two circuits.

For a two wire metallic circuit the inductance will be double the difference between the expressions (7) and (8) or

$$L = \mu_1 + 2\int_r^{r_{12}} \frac{2\mu}{x}\,dx = \mu_1 + 4\mu \log \frac{r_{12}}{r}. \qquad 9$$

For a single wire at height h above the earth the inductance is

$$L = \frac{1}{2}\mu_1 + 2\mu \log \frac{2h}{r}. \qquad 10$$

These expressions in henries per mile are---

$$L = \left(0.1609 + 1.482 \log_{10} \frac{d}{r}\right) 10^{-3}. \qquad 11$$

$$L = \left(0.08047 + 0.7411 \log_{10} \frac{2h}{r}\right) 10^{-3}. \qquad 12$$

where $\mu_1 + \mu_2$ are unity.

The field of force without a two wire metallic circuit is, from (2)

$$F = 2I\left(\frac{1}{r_{1x}} - \frac{1}{r_{2x}}\right). \qquad 13$$

* Demonstration due to Jackson Alternating Current Machinery p-140

where the point X is perpendicularly distant r_{1x} from the first and r_{2x} from the second wire. From this the field intensity along the X-axis in Fig 2 is proportional to

$$y = \frac{1}{a+x} + \frac{1}{a-x}. \qquad 14$$

for points without the wires, and

$$y = \frac{2x}{r^2}. \qquad 15$$

for points within the wire. Figure 3 is plotted from (14) and (15).

Mr. Fowle goes on to consider two two-wire metallic circuits and derives expressions relating to the mutual inductance between them, as follows:

"Consider the case of two wire metallic circuits, as shown in cross-section, Fig. 4. The expression for mutual inductance follows at once from expression (8).

$$M = \int_{r_{13}}^{r_{14}} \frac{2\mu}{x}\,dx - \int_{r_{23}}^{r_{24}} \frac{2\mu}{x}\,dx. \qquad 16$$

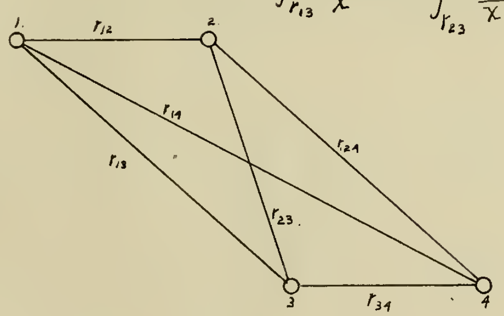


Fig. 4

$$M = 2\mu \log \frac{r_{14}\, r_{23}}{r_{13}\, r_{24}}. \qquad 17$$

In henries per mile

$$M = \left(.7411 \log_{10} \frac{r_{14}\, r_{23}}{r_{13}\, r_{24}}\right) 10^{-3} \qquad 18$$

The foregoing expressions for sélf and mutual inductance may be established from the standpoint of the kinetic energy of an electro-magnetic system as shown by--

Maxwell, Vol. II, Art. 685,- and Heaviside Electrical Papers, Vol. I, page 100.

The following curves were plotted by Mr. Fowle to show that constants of mutual inductance depend on the relative position of the wires.

$$\frac{M}{2} = \log \frac{r_{14}\, r_{23}}{r_{24}\, r_{13}} \qquad 19$$

If the circuit 3,4 always maintains a horizontal position in Fig. 5, and the coordinates of P ar X and Y, P being constrained to move in a circle, (19) becomes

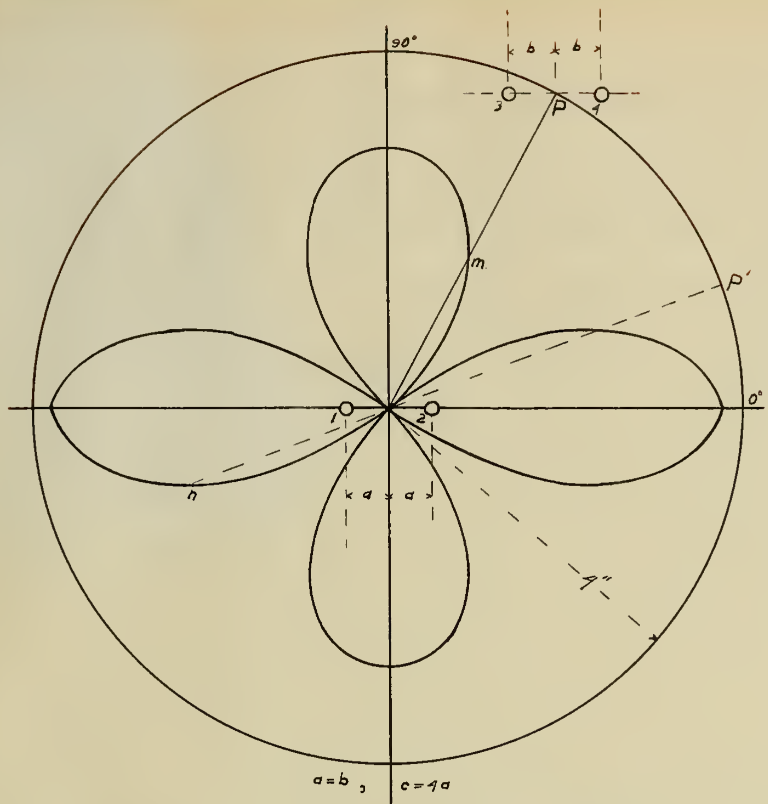
$$\frac{M}{2} = \frac{1}{2} \log \frac{[(a+b)^2 + e^2] - [2(a+b)x]^2}{[(a-b)^2 + C^2] - [2(a-b)x]^2} \qquad 20$$

where C is given by the locus of P

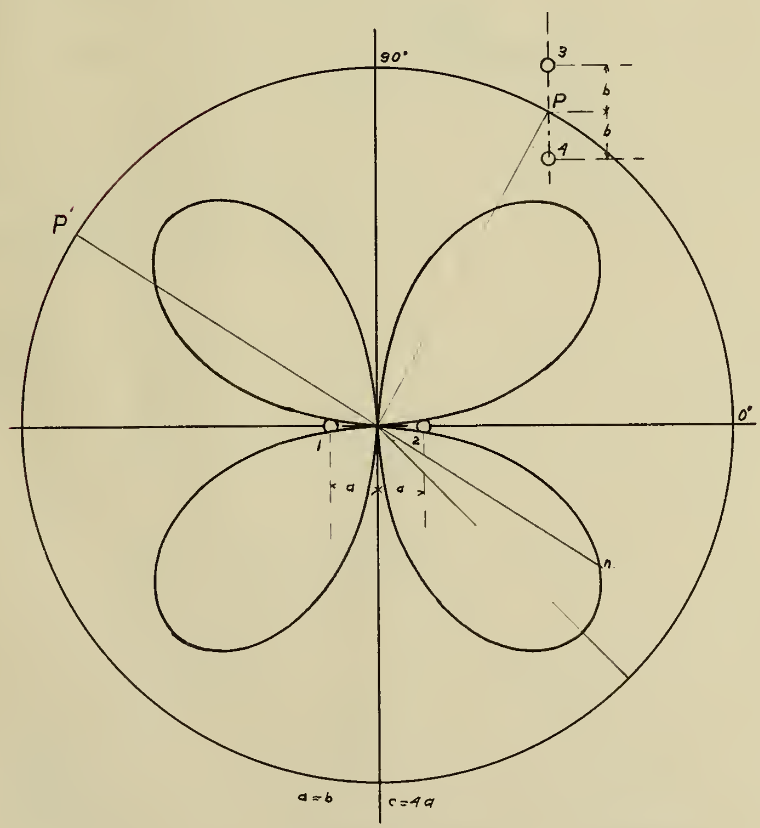
$$X^2 + Y^2 = C^2. \qquad 21$$

If the circuit 3,4 maintains a vertical position, Fig. 6, and the locus of P is again a circle

$$\frac{M}{2} = \frac{1}{2} \log \frac{(x^2-a^2)^2 + (x+a)^2(y+b)^2 + (x-a)^2(y-b)^2 + (y^2-b^2)^2}{(x^2-a^2)^2 + (x-a)^2(y+b)^2 + (x+a)^2(y-b)^2 + (y^2-b^2)^2}. \qquad 22$$



Scale Log_{10} 10 = 30." Fig. 5.



Scale Log_{10} 10 = 30." Fig. 6.

An examination of these curves will show that there are four points in a revolution where M is zero. In the condition where 3-4 always maintains a horizontal position the points are at 45°, 135°, 225° and 315°. Where the circuit 3-4 always maintains a vertical position M becomes zero at 0°, 30°, 180° and 270°. Mr. Fowle states that it is possible to introduce a third circuit and arrange the position such that the mutual inductance is zero for any two and thence for all, but when the number of circuits becomes greater than three it is impossible to arrange the position of the circuits such that the mutual inductance is zero, and this discussion is only valuable because of its instructiveness.

The electrostatic induction*

A very interesting set of experiments was carried on by Mr. J. J. Carty which show the effects of electrostatic induction, and it seems that they should be described in connection with this paragraph.

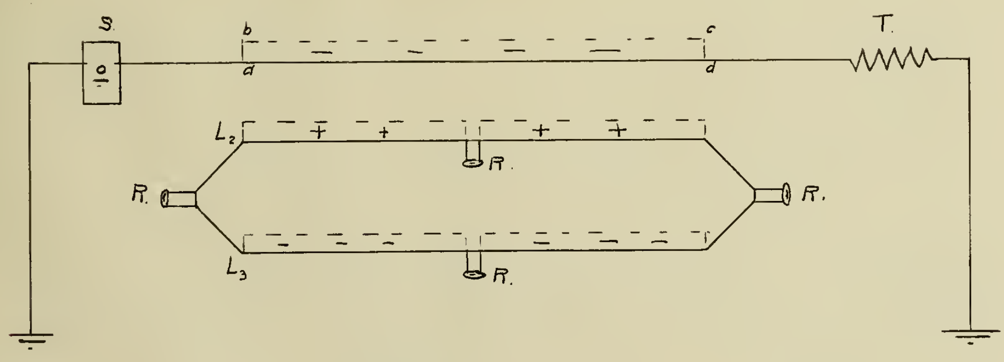


Fig. 7

* For a theoretical discussion, see O. Heaviside, Vol. I, pages 42-47

In figure 7 L^2 and L^3 are two well insulated copper wires 500 feet long and three feet apart. Telephone receivers are placed at R as shown in the figure. L' is a form of disturbing wire which he used. It was placed within 1/3 inch from L^2, T and S being a Blake transmitter, was operated by means of a tuning fork, and a disturbance was noted in each of the end telephones, but at the two central receivers no noise was appreciable. This was his first experiment and it was explained by assuming that the disturbance was due to electrostatic induction, as follows: Suppose that there is a negative charge on L represented by the rectangle abcd. This has induced a positive charge on L^2 and a negative charge on L^3. Since L^2 and L^3 are not insulated from each other these charges will tend to neutralize or run together which will cause a current to flow through the end receivers, but no current will flow through the central receivers providing they are centrally located.

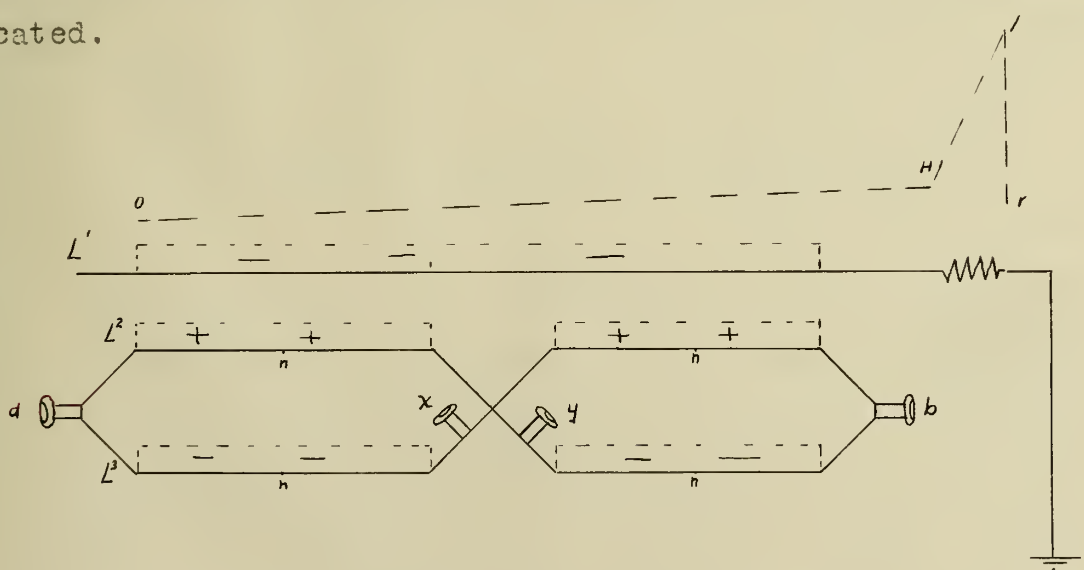


Fig. 8.

A second experiment is shown by Fig. 8. One end of the wire L' was disconnected from the ground which eliminated all possibility of electromagnetic disturbance because the fall of potential as distributed over the wire is represented by OK1R. The wires L^2 and L^3 are connected the same as before with the exception that one transposition is effected thus crossing wires L^2 and L^3 at the center. As the transmitter is caused to vibrate in this case the amount of noise was decreased in a and b and a noise was heard in x and y. This experiment further proves that the disturbance is caused by electrostatic induction. In this case the mutual points have been shifted to the positions represented by n and a current passes through all four of the receivers.

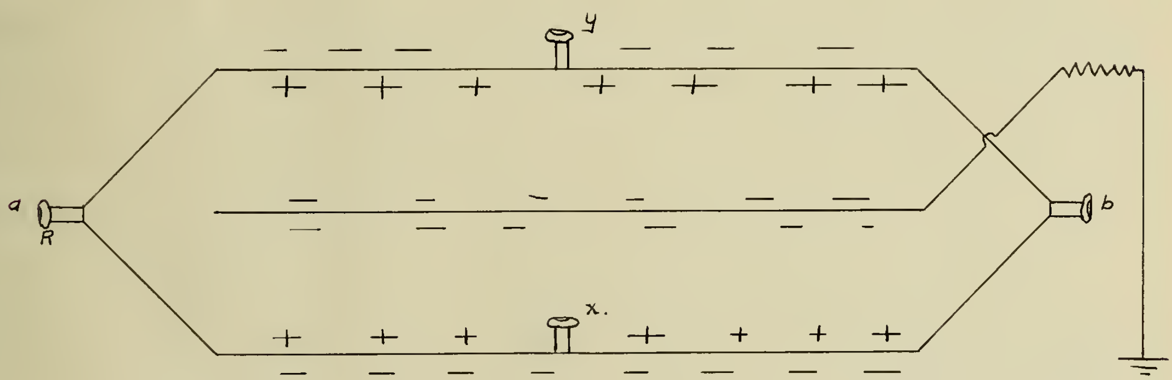


Fig. 9.

A third experiment performed by Mr. Carty is as follows: Fig. 9 shows the relative position of the wires. In this case the disturbing wire was placed between the wires L^2 and L^3 and at an equal distance from each of them. As the disturbing wire was energized plus and minus charges were

induced on the opposite sides of wires of L^2 and L^3 as shown in the figure. Here the flow of current is all lateral and no current passes through any of the telephones and in consequence no noise was heard.

In his next experiment the receiver (y) was removed and the wire L^3 was grounded at that point (y). A noise was heard in both end receivers and the receiver x was silent. This shows that the disturbing current passed from x (the neutral point) through both end receivers and thence to the ground through y. The flow of current in this case was longitudinal, there being a + charge induced on each of the wires L^2 and L^3 and a - charge induced on the earth from the negatively charged wire L'.

A fourth experiment, as performed by Mr. Carty, was similar to the preceding experiments except at the telephones a and b there were provided ground keys such that that point of the circuit could be grounded at will. The disturbing wire was left at an equal distance from L^2 and L^3. As the transmitter was caused to vibrate no sound was heard in any of the telephones, but upon closing one of the ground keys a noise was heard in the two receivers x and y, but no noise was heard at the telephones a and b.

All these experiments go to show very conclusively that the electrostatic disturbance is large and should be investigated further. Mr. Carty draws a wrong conclusion from his experiments, however. He assumed that the conditions he had were general and that because the disturb-

ances in his experiment were electrostatic that in all cases electromagnetic disturbances were negligible in all cases.

Mr. Cohen, in his article, very satisfactorily proves that Mr. Carty's conclusions were correct for his conditions, but that for long lines of such length that the resistance and inductance of the instruments has little effect on that of the line.

Mr. Louis Cohen, in a paper presented before The American Institute of Electrical Engineers, June 25, 1907, on Inductive Disturbances in Telephone Lines, by means of a mathematical demonstration shows the ratio of electrostatic to electromagnetic induction for lines of various lengths. Starting with the differential expression

$$L_1 \frac{dx}{dt} + R_1 x + M \frac{dy}{dt} + \frac{dV_1}{ds} = 0 \qquad 33$$

$$L_2 \frac{dy}{dt} + R_2 y + M \frac{dx}{dt} + \frac{dV_2}{ds} = 0 \qquad 34$$

In which x and y are currents, V_1 and V_2 are potentials at any point along the two lines, L_1 denotes the self inductance, and R_1 = resistance. Mr. Cohen derives an expression for the currents in the lines due to electrostatic and electromagnetic induction as follows

$$y_1 = E_p \sqrt{A^2 + B^2 - 2AB \cos(\phi - \phi_1)} \sin(pt + \phi) \qquad 35$$

Where, $A = \dfrac{c - c_{12}}{\sqrt{(\alpha_1^2 + \beta_1^2)(2\cosh 2\beta_1 l - 2\cos 2\alpha_1 l)}}$

36

$$B = \frac{C + C_{12}}{(\alpha^2+\beta^2)(2\cosh 2\beta l - 2\cos\alpha_1 l)} \qquad 27$$

$$\tan\phi = \frac{A\cos\phi_1 - B\cos\phi}{A\sin\phi_1 - B\sin\phi} \qquad 28$$

The maximum value of current will be

$$E_p \quad A^2+B^2-2AB\cos(\phi-\phi_1) \qquad 29$$

To find the ratio between electrostatic and electromagnetic induction the value of y_l is calculated as given by (25) first on the supposition that M is 0 and second on the supposition that $C_{12} = 0$. The values of the varicus electrical coefficients were taken from O. Heaviside's Collected paper, Vol. I; page 44 and 101, and are as follows:

$$L = \frac{1}{2} + 2\log\frac{2h}{r} \qquad 30$$

$$M = \log\frac{d^2+(h_1+h_2)^2}{d^2+(h_1-h_2)^2} \qquad 31$$

$$C_1 = \frac{2\log\frac{2h}{r}}{\left(2\log\frac{2h}{r}\right)^2-\left(\log\frac{d^2+4h^2}{d^2}\right)^2} \qquad 32$$

$$-C_{12} = \frac{\log\frac{d^2+4h^2}{d^2}}{\left(2\log\frac{2h}{r}\right)^2-\left(\log\frac{d^2+4h^2}{d^2}\right)^2} \qquad 33$$

The formulas apply to the case of parallel suspended wires where h is the height above the ground, (d) is the distance between the wires, and r is the radius of the wires.

Mr. Cohen considers an example. Assuming that the two wires are 1.25 cm. apart and about 1000 cm. above the ground the radius of each wire being 0.1 cm, he then finds values for the constants as follows:

L = 0.00203 henry	per	kilometer	
M = 0.00147	"	"	"
C = 0.0118 M.F.		"	"
C = 0.0088 M.F.		"	"

R = 3 ohms per kilometer approximately. With these values Mr. Cohen calculated the maximum of the current y 1 as given from equation (25), first assuming that the M = 0, and then assuming that $C_{12} = 0$. He tabulated the ratios of the two forms as follows:

	$\frac{e.s.}{e.m.}$
0.1 Km--	0.02
100.0 Km--	0.44
1000.0 Km--	1.6

An examination of the table shows that for short lengths the electrostatic induction is much greater than the electromagnetic induction, but for long lengths of line the electromagnetic induction even becomes greater than the electrostatic.

In considering Mr. Carty's experiments Mr. Cohen states that there were in his case two lines .1 Km long stretched side by side at a distance of about 1 cm, and that there were three telephone receivers in the second line. His approximate solution of the problem is as follows: Consider the telephone receivers as distributed inductance and resistance. If the inductance of each receiver is .05 henry and its resistance 50 ohms, then for a short line the inductance per unit length will be $L = 1.5$ henry and $R = 1500$ ohms. Solving his former equation using these new constants he shows that the electromagnetic induction is practically zero, and that only the electrostatic induction is appreciable. This confirms Mr. Carty's experiments.

Leakage. The extent to which leakage from the line to the ground through broken insulators, limbs of trees, etc., causes disturbances, is very little known.

It is the opinion of Mr. P. M. Lincoln that the greater the potential and the less the capacity between the telephone wires and the ground the greater the disturbance. Mr. Fowle on the other hand believes that this is erroneous.

It has been reported that on the line between Springfield and Lincoln wet weather does not seem to effect the telephones or cause any disturbance when the wires are free. If the wire rests on a cross-arm or on the limb of a tree it is reported that noises are heard. It seems that this in a way would confirm Mr. Lincoln's view. In a discussion of Mr. Lincoln's paper Mr. Mershon makes the statement that

he does not think currents taken off at bunched points along the line would effect noises in the 'phones.

An interesting occurance was noted recently. The I.T.S. people were unable to talk over their train dispatching circuit on the Peoria and Bloomington line when it was first put up. The wire at the top of the pole which was intended for lightning protection did not have the ground connections made at this time. When this wire had been grounded in a few places they were able to talk fairly well and when the ground had been made every six poles conversation was very satisfactory. Mr. Lincoln would explain this by stating that the potential between the telephone and the ground had been decreased by increasing the capacity between the two.

Mr. Fowle states that the effect was brought about by reducing the zone of the static field. He also makes the assertion that if the wire were moved closer to the trolley that the inductive disturbances would be still further decreased.

Unbalanced Lines and Terminals. It often happens that the two wires of a telephone line are unbalanced, that is, the lines may be situated in a position such that one wire may have induced upon it a potential far greater or less than that induced on the other wire. In such a case a current would pass through the line from the point of higher potential to that of the lower potential, and should this current flow through the telephone receiver a disturbance would un-

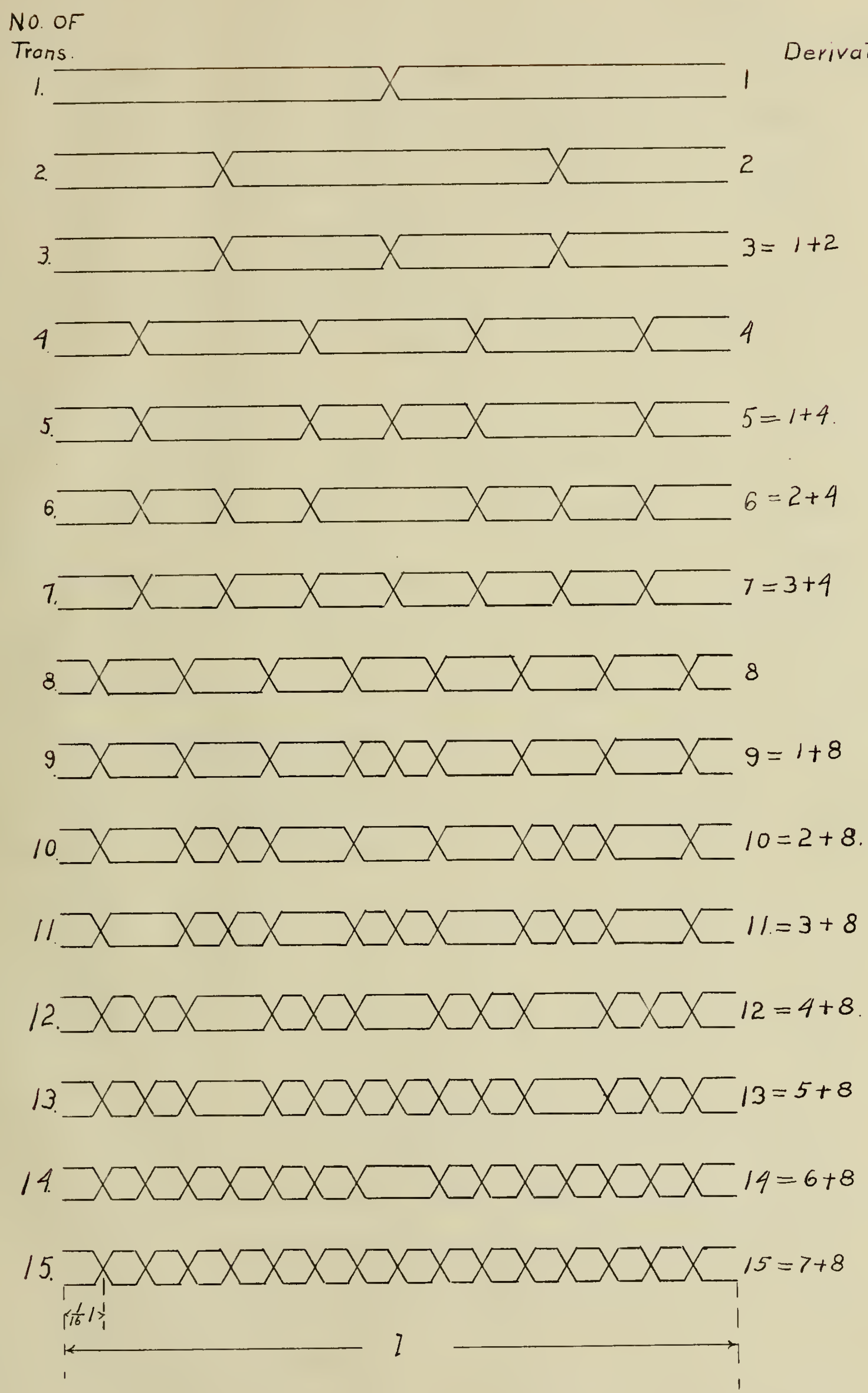
doubtedly be the result.

Another case might be that in which the line itself acts as a condenser receiving a charge on a portion of the line and a lesser charge at other sections. In such a case an equalizing current would flow and cause disturbances in the telephone receivers.

Methods Suggested as Remedies for Inductive Disturbances---

There have been numerous solutions to the inductive problem and it seems well that the more important methods be described here.

Transposition. The simplest case where transposition is necessary is in that of two or more parallel telephone lines. In this case the transposition is merely to prevent cross talk between the lines. The number of transpositions that should occur per mile of line has been determined by experience. It would be a hard matter to develop theory in treatment of the matter of induction between telephone wires alone. The conditions are so varied. It has been found that with two-mile sections, transposed at the center, the cross talk is distinguishable with transmission sufficiently powerful for 1000-mile service. Half or quarter-mile sections transposed at the center are found to give satisfaction. If it should happen that there are several parallel telephone circuits on the same pole line, it is necessary to devise different types of transposed circuits. The following figure is one presented by Mr. F. F. Fowle and represents standard practice.



NO. OF Trans.
Derivation.
1.
1
2.
2
3.
3 = 1+2
4
4
5.
5 = 1+4.
6.
6 = 2+4
7.
7 = 3+4
8.
8
9.
9 = 1+8
10.
10 = 2 + 8.
11.
11. = 3 + 8
12.
12 = 4+8.
13.
13 = 5+8
14.
14 = 6+8
15.
15 = 7+8
1/16 l
l

"The exposure, as it is termed, of circuit 1 to circuit 2, is 1/4; of 1 to 3, is 1/4; of 2 to 3, is 1/2; because a transposition at the junction of two sections, each transposed at its center, has almost no beneficial effect. The exposure 1 to 5 is 1/8; of 2 to 6, and 3 to 7, 1/8; of 2 to 8, and 3 to 9, 1/16, and so on."

The derivation of these various types is very simple--the first three are obvious. The fifth is derived by a combination of 1 + 4 and so on.

Where the telephone lines are paralleled by power lines the solution is a little more difficult. In such cases it is necessary to consider all portions of the line where abrupt changes or pressures occur. It is advisable to make a transposition of the telephone line at each transformer, at each section where a branch is taken off or at every point where the transmission line makes a right angle turn and leaves the telephone line. Such sections as these undoubtedly will be of various lengths and the problem of properly dividing these lengths up into transposition sections requires considerable care. The regular cross talk transposition should be removed from such a section. If the portion between abrupt changes in the power line are long enough to include several cross talk sections the transpositions should be opposite the junction of two power sections, at the point where the disturbing current and pressure change in magnitude or phase.

Not infrequently high pressure systems are transposed for their internal protection. When telephone circuits

are on such lines the transposition of the power circuit may be made use of to reduce inductance in the telephone circuit. A second remedy suggested is due to Mr. Fowle. This applies exclusively to protection against the trolley. Mr. Fowle suggests finding a section from each end in such a manner that the induction will be all or partly neutralized. This can be brought about by feeding a car, which is for instance 1/4 the distance between two stations, 3/4 of its current from the nearer station and the 1/4 from the farther station. This method seems very practical, but its chief objection is that the total expense of preventing the inductive disturbances comes on the railway company. In cases where the railway company is protecting its own telephone lines this method is advised.

If a return conductor should be placed on the mast arm as near to the trolley as practicable and be grounded to the rails at frequent intervals it would counteract the field sufficiently to cut down the induction to a negligible amount. The same difficulty arises with this scheme as with the latter. It would be difficult to get the railways to adopt it because it throws all the expense of preventing the induction on the railway company instead of the telephone companies where they think it should be.

A patent issued June 16, to Mr. A. H. Armstrong discloses a means for preventing the disturbing effect of static induction. The invention makes use of the catenary which is usually employed in the suspension of trolley wires. He provides means for maintaining this catenary at a poten-

tial approximately equal but opposite in time phase to that of the trolley by use of a transformer whose middle point is grounded to the rail and whose two terminals are connected respectively to the catenary and the trolley wire. Under this condition a telegraph or a telephone wire located in proximity to the trolley wire will be subject to the static effect of both the trolley wire and the catenary, and owing to the fact that the voltage of these two conductors is, at every instant, approximately equal but opposite the resultant effect on the adjacent telegraph or other wires will be nil. It will be seen that this method eliminates only the electrostatic induction,and it was learned from Mr. Louis M. Cohen that at times the electromagnetic induction could be much the greater of the two.

A British patent of the General Electric company provides for a return conductor connected in shunt to the rails which is placed near the wire to be protected. This will neutralize the electromagnetic induction and since the rails are grounded the capacity between the earth and the wire to be protected will be greatly increased. This will decrease the potential between the telephone wire and the ground and the electrostatic induction will be greatly decreased.
A resistance may be required in the shunt circuit to keep the current down to a required amount. For the same purpose a transformer may be used, the primary winding being placed in series with the rail,and the secondary with the neutralizing conductor.

A paper communicated from the German Imperial Telegraph Experiment Station and read before the Berlin Electrical Society gives the following account:

On some parts of 34000 volt, three phase transmission system in the Urft Valley district telephone lines are run within the neighborhood of transmission lines and serious disturbances due to induction of electrostatic charges were experienced. On one telegraph line which had formerly an earth return the distrubances disappeared after the line had been equipped with a full metallic circuit. But on branch connections of this line which are equipped with single metallic conductors, the disturbances remained. They were due to electrostatic charges induced on the two-conductor main telephone lines. By providing a proper earth connection for the latter the trouble in the branch connections was removed. In this connection, extended experiments were made by the telephone department. It was found that while electrostatic induction from the transmission line appeared to have comparatively little effect on the telephone line, measurable electrostatic charges were induced from the former on the latter even if the distance between the two was as much as 800 yards. If the currents produced by this effect in the telephone lines are of a magnitude of 10 amp. (see F.F.Fowle-- Transposition of Conductors), the telephone lines must be equipped with full metallic circuits.

This construction removes the difficulties of the transmission of sound in the line itself,but the electrostatic

charges are not prevented. If the line has single conductor branch connections trouble will be experienced in these. Disturbances will result if the E. M. F. induced in the main line exceeds 5 volts. In such a case it is necessary to provide the main line with suitable earth connections. Besides the trouble because of the difficulties in the transmission of speach there is danger to life from the high potential which the branch circuits may receive. Under normal conditions the potential between any conductor of a three phase transmission circuit and the ground is 58 % of the line potential with either Y or delta connection, but the neutral may drift so as to increase the potential with an underground system. If one branch is partly or completely grounded the potential between the other two branches and the ground may be the total line voltage. With a grounded neutral Y system the ground is a short circuit of the transformer on the grounded branch, and its transmission becomes inoperative. There is a further danger from grounding which should be considered. In case of trouble on circuits, current may flow through the ground to the neutral. In this flowing it will assume the path of the least resistance so that if telephone lines which have normally low resistance to ground parallel the transmission line the current will flow along these wires often with disasterous results to the circuits.

Two cases of trouble are liable to give these conditions. First,- where the middle points of the high tension

windings of transformers are grounded the opening of one or two of the three transmission wires will cause current to flow through the ground. Second,- a high resistance ground on a transmission line will probably short circuit a transformer and cause current to flow through the ground and the neutral. Fig. (10) shows further difficulties which might arise-- let T represent the trolley wire and R R the rails forming the return circuit for the system.

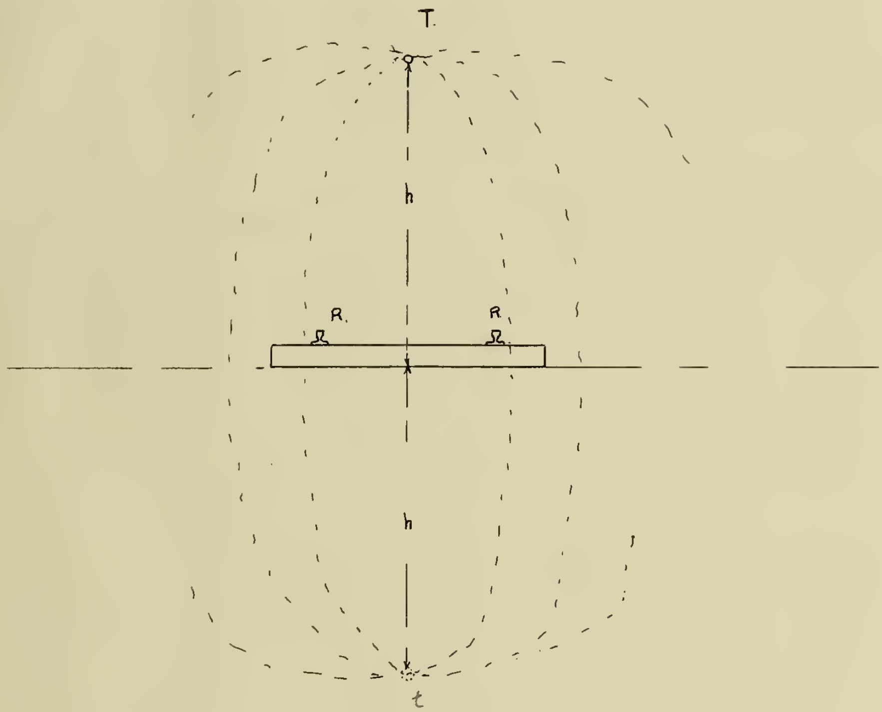


Fig 10.

If there be poor bonding along the rails a portion of the current will return through the ground and the path of this current will be along the image (t) of the trolley wire (T) which is at a distance (h) below the surface of the earth. It will be seen that this increased distance between the two conductors T and t will increase the zone of the field about the circuit and the number of lines of force that will

intersect any neighboring telephone circuit will be greatly increased, thus increasing the induction. Should the telephone circuit be well grounded a portion of the current might pass through the telephone wires. It is therefore important that all bonds be in good condition.

These are only minor points effecting the conditions described in this brief report. They, however, tend to show one how little is known of this expansive subject, and should these few facts collected here be of use of some one who enters this field of research, the object of this paper will be realized.

The writer is indebted to T. H. Amrine and his notes for the information given in this paper.

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